# Global fits for top operators

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# Global EFT fits in top physics

## Current Status

### LHC Top WG recommendation

Interpreting top-quark LHC measurements
in the standard-model effective field theory

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**Abstract**

This note proposes common standards and prescriptions for the effective-field-theory interpretation of top-quark measurements at the LHC.

arXiv:1802.07237

Baseline flavour scenario singles out the 3rd generation

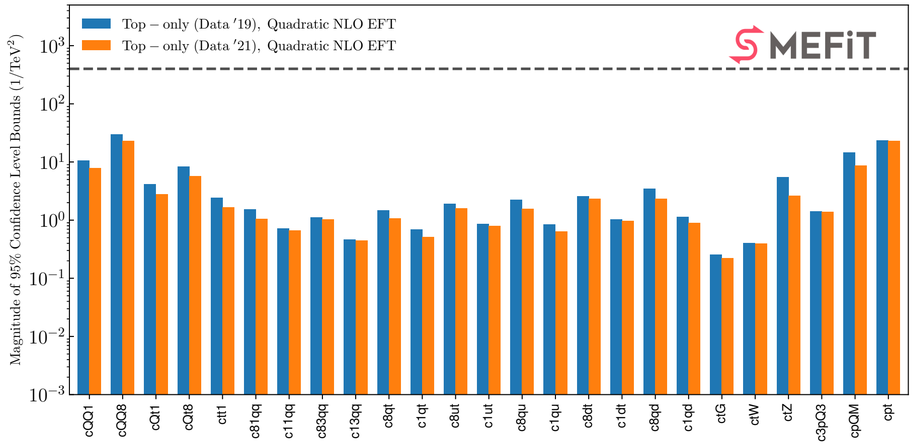
$$U(2)_q \times U(2)_u \times U(2)_d$$

| | |
|---|---|
| four heavy quarks | $11 + 2$ CPV |
| two light and two heavy quarks | 14 |
| two heavy quarks and bosons | $9 + 6$ CPV |
| two heavy quarks and two leptons | $(8 + 3$ CPV$) \times 3$ lepton flavours |

### Current LHC fits

### ~30 coefficients

| Category | Processes |
|---|---|
| Top quark production<br>**parton level** | $t\bar{t}$ (inclusive)<br>$t\bar{t}Z$, $t\bar{t}W$<br>single top (inclusive)<br>$tZ, tW$<br>$t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$<br>**Total** |




Bounds vary between operators

**ttZ ones and 4-heavy ones loosely constrained**

Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, EV and Zhang arXiv:2105.00006

Hartland, Maltoni, Nocera, Rojo, Slade, EV and Zhang, arXiv:1901.05965 (SMEFiT analysis)

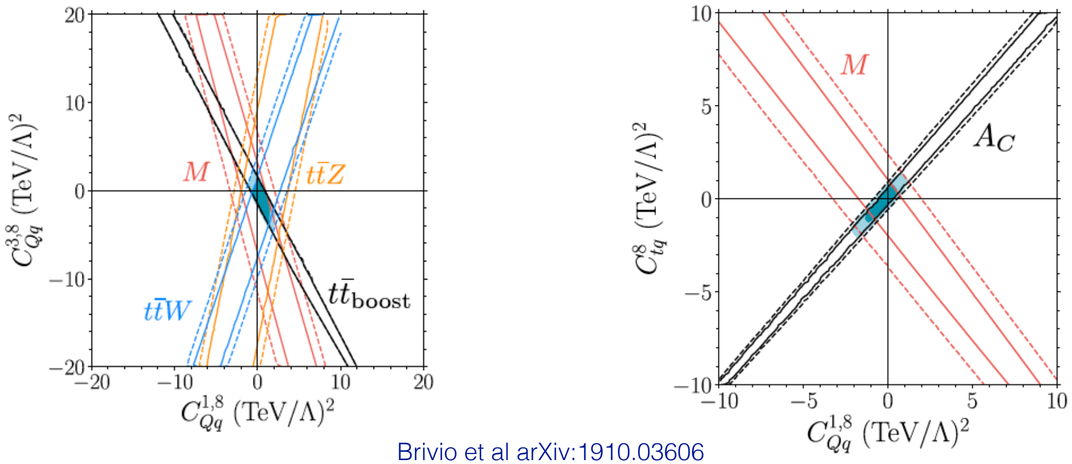
Brivio, Bruggisser, Maltoni, Moutafis, Plehn, EV, Westhoff, Zhang arXiv:1910.03606 (SFitter analysis)

# Top-quark 4-fermion operators

## How to deal with them?

- Lots of them: Baseline CP-even scenario has 25

1. 4quarks: we need lots of different observables





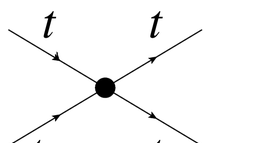


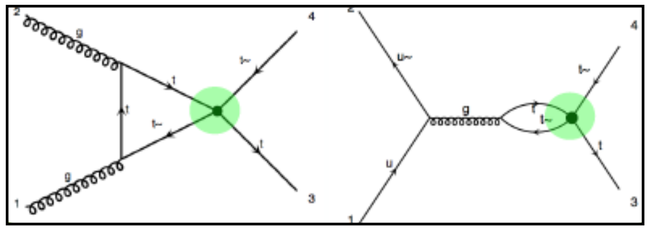
Brivio et al arXiv:1910.03606

2. 2tops-2leptons not included in global fits:
   ILC: Durieux et al arXiv:1907.10619
   LHC: CMS-PAS-TOP-19-001

3. Some are particularly tough:
   4-heavy operators (4tops & ttbb) -
   indirect (one-loop) constraints?

$$\mathcal{O}_{QQ}^{8} = (\bar{Q}\gamma^{\mu}T^{A}Q)(\bar{Q}\gamma_{\mu}T^{A}Q)$$
$$\mathcal{O}_{QQ}^{1} = (\bar{Q}\gamma^{\mu}Q)(\bar{Q}\gamma_{\mu}Q)$$
$$\mathcal{O}_{Qt}^{8} = (\bar{Q}\gamma^{\mu}T^{A}Q)(\bar{t}\gamma_{\mu}T^{A}t)$$
$$\mathcal{O}_{Qt}^{1} = (\bar{Q}\gamma^{\mu}Q)(\bar{t}\gamma_{\mu}t)$$
$$\mathcal{O}_{tt}^{1} = (\bar{t}\gamma^{\mu}t)(\bar{t}\gamma_{\mu}t)$$



Degrande, Durieux, Maltoni, Mimasu, EV, Zhang arXiv:2008.11743

Also at e+e- Banelli et al arXiv:2010.05915

4. Non-interfering operators: leading constraints from dim6^2. Is there a way to avoid that?

# Unavoidable Higgs-top connection

## Operators connecting Higgs and top

$$O_{\varphi Q}^{(3)} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}^I_\mu \varphi\right)(\bar{Q}\gamma^\mu \tau^I Q)$$
$$O_{\varphi Q}^{(1)} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi\right)(\bar{Q}\gamma^\mu Q)$$
$$O_{\varphi t} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi\right)(\bar{t}\gamma^\mu t)$$

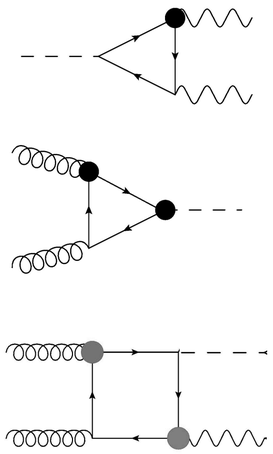
current

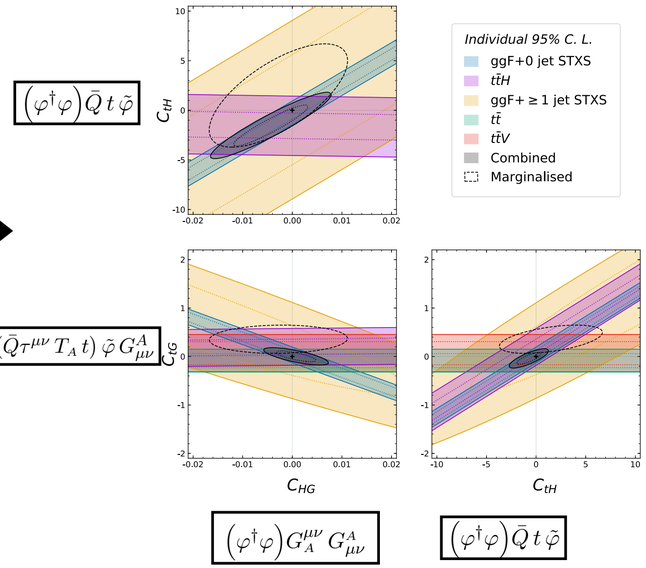
$$O_{tW} = y_t g_w (Q\sigma^{\mu\nu}\tau^I t)\tilde{\varphi} W^I_{\mu\nu}$$
$$O_{tB} = y_t g_Y (\bar{Q}\sigma^{\mu\nu} t)\tilde{\varphi} B_{\mu\nu}$$
$$O_{tG} = y_t g_s (\bar{Q}\sigma^{\mu\nu} T^A t)\tilde{\varphi} G^A_{\mu\nu},$$

dipoles

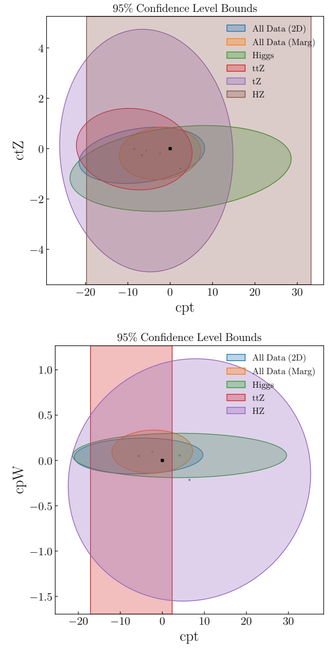
$$O_{t\phi} = y_t^3\left(\phi^\dagger\phi\right)(\bar{Q}t)\,\tilde{\phi}$$

Yukawa






Ellis, Madigan, Mimasu, Sanz, You arXiv:2012.02779




Ethier et al arXiv:2105.00006

Future colliders below tt/ttH threshold only source of info on top is this kind of loops

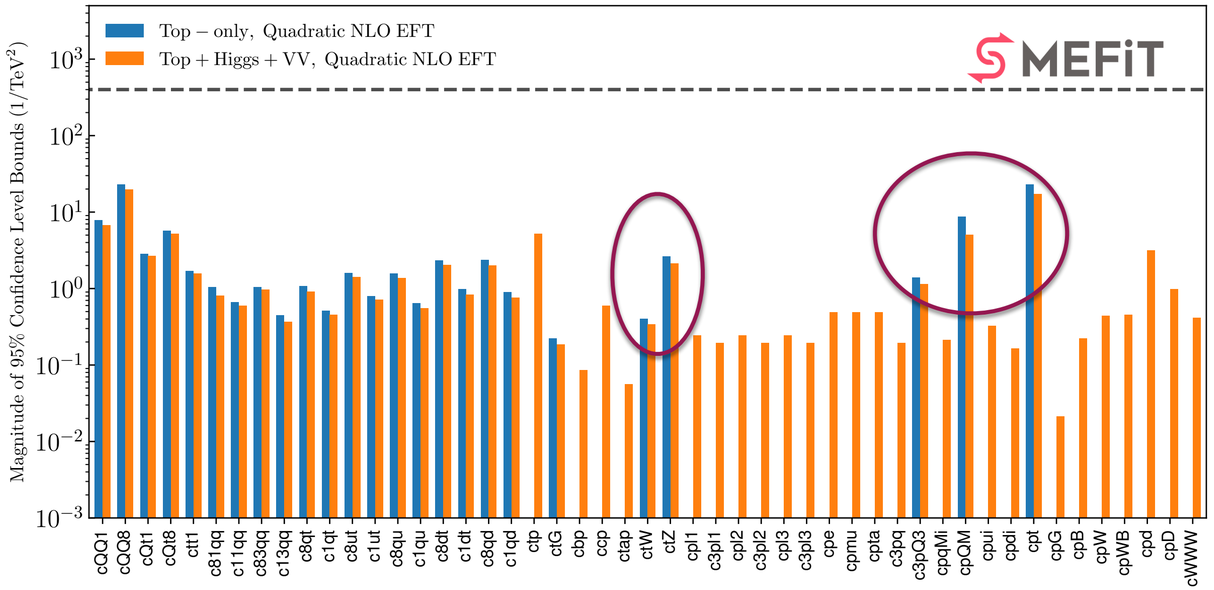
e.g CEPC Durieux, Gu, EV, Zhang arXiv:1809.03520

# Top-Higgs interplay

## Global fits in the top+Higgs sector

~50 coefficients under U(2)q ×U(2)u × U(3)d

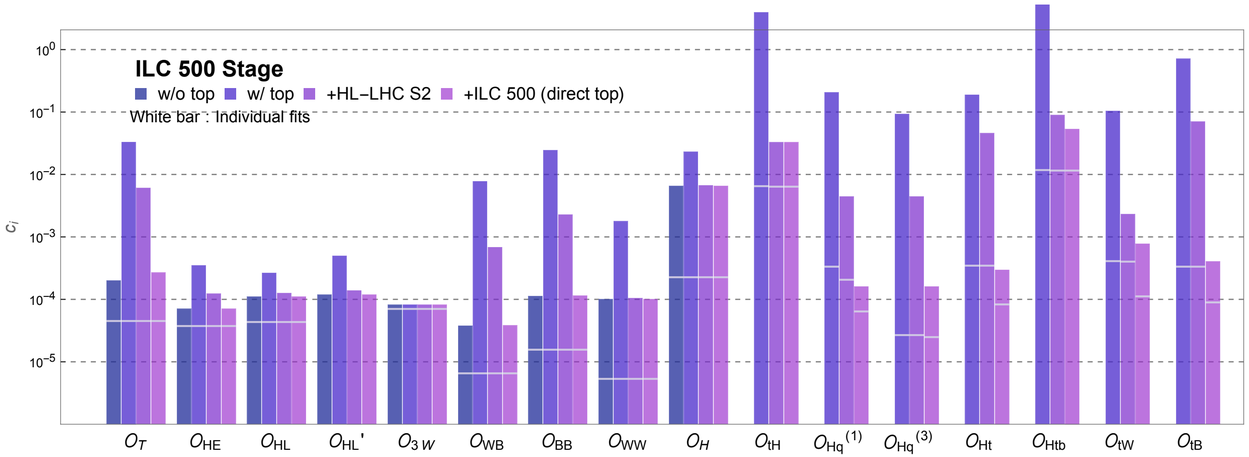
**LHC: Need Higgs, top, diboson and EWPO**




Higgs data improves certain top operator bounds

Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, EV and Zhang arXiv:2105.00006

## Future colliders: 29 parameters (no 4F)




Adding top: Jung, Lee, Perello, Tian, Vos arXiv:2006.14631

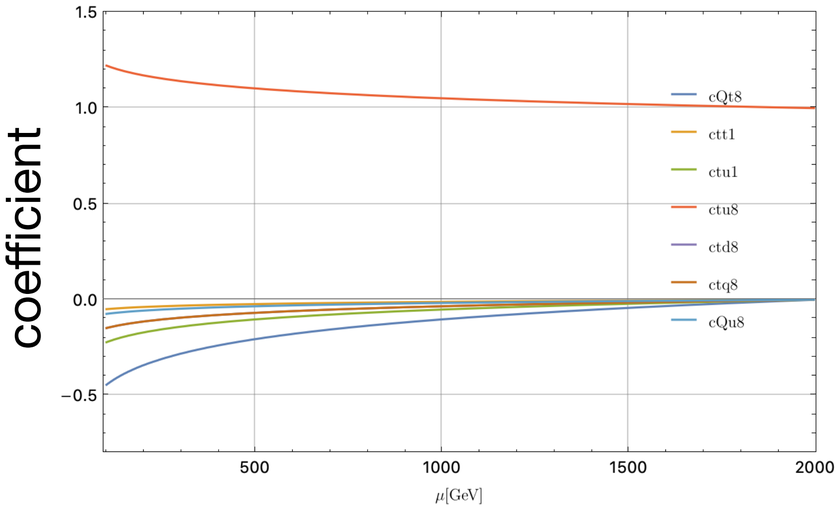
- Need HL-LHC to restore precision in Higgs
- Need above the threshold runs at ILC to precisely determine all

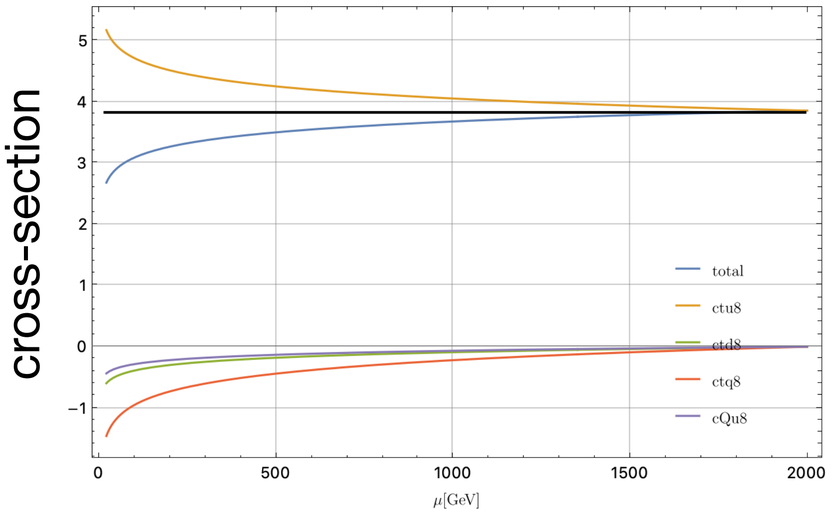
Can we envision a really global but constraining fit?

# RGE effects

## Can they matter?

- Processes with different scales involved:
  - single top, top pair, 4 tops
- Distributions for top pairs reaching ~2TeV
- Running typically ignored in global fits
- How do the coefficients change within typical scale ranges and can this affect the fit?




Aoude, Maltoni, Mattelaer, EV in preparation

# Global EFT fits in top physics

## Future directions (1)

Improving LHC top fits:

- Additional/more sensitive top observables: going beyond parton level, spin correlations, production+decay
- 2quark-2lepton operators in global fits (by off-shell ttll measurements)
- CP-violation & different flavour assumptions
- RGE effects
- Systematic exploration of 1-loop effects (NLO QCD/EW)
- Systematic study of EFT uncertainties (higher order terms in 1/Λ)
- EFT in backgrounds, when do we have to worry?

} Part of LHC EFT WG discussion (see also G. Durieux's talk)

# Global EFT fits in top physics

## Future directions (2)

Future colliders:

- Unlike the Higgs and EW sectors, limited work on HL-LHC, FCC-hh projections for top operators, need for global analyses
- Truly global fits for future colliders as typically only subsets of operators considered
- Combination of top+Higgs for future colliders, including 1-loop effects
- Systematic comparison prospects of different future colliders (ILC, FCC-ee, CEPC and different energies), using a common setup and common set of operators